Fermi National Accelerator Laboratory

FERMILAB-Conf-96/245-E
D0

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August 1996

Published Proceedings of the *XI Topical Workshop on pbar p Collider Physics*,
Abano Terme (Padova), Italy, May 26-June 1, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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MEASUREMENT OF $W + 1$ JET/$W + 0$ JETS CROSS SECTIONS

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Abstract

A preliminary measurement of the ratio $W + 1$ Jet/$W + 0$ Jets in $\overline{p}p$ collisions at $\sqrt{s} = 1800$ GeV is presented. A comparison to next-to-leading order QCD finds the theory to be well below the experimental ratio even after accounting for the systematic uncertainties of the measurement. In addition, a study of both the measured and theoretical ratios as a function of minimum jet transverse energy (E_T) shows that the theoretical predictions are systematically lower than the data.

(Submitted to the proceedings of the *XI Topical Workshop on $\overline{p}p$ Collider Physics, Abano Terme, Italy, May 26th-June 1st, 1996.*)

I. MOTIVATION

Measurements of $W + n$ Jets production cross sections in $\overline{p}p$ collisions is a valuable way of testing QCD theory. In both leading order (LO) and next-to-leading order (NLO) QCD theory, one naively expects that the ratio of $W + 1$ Jet/$W + 0$ Jets cross sections will be proportional to the strong coupling constant α_S. This proportionality previously has been used by UA2 [1] and UA1 [2] at $\sqrt{s} = 630$ GeV to extract a value of $\alpha_S(M_W{}^2)$. DØ has published [3] a measurement of the $W + 1$ Jet/$W + 0$ Jets cross sections at $\sqrt{s} = 1800$ GeV in $\overline{p}p$ collisions using data from the 1992-1993 collider run of the Fermilab Tevatron. One surprising result was that the NLO QCD predictions using the DYRAD [4] Monte Carlo for the ratio showed no real α_S dependence, in sharp contrast to the UA2 and UA1 results which are at a lower center of mass energy. Having a higher center of mass energy allows DØ to probe a lower momentum fraction range for the initial state partons and thus makes DØ more sensitive to the gluon distribution. This increased sensitivity to the gluon distribution is important to exploit since the gluon distribution inside the proton is not well constrained. The result presented here is from the 1994-1995 run and represents a factor of six increase in statistics over the previous result.

II. THEORY

The diagram for $W + 0$ Jet production in leading order QCD is the $q\overline{q}$ annihilation diagram (see Figure 1). This annihilation diagram does not have any strong interaction vertices and thus has no α_S dependence. The diagrams for $W + 1$ Jet production at leading order, shown in Figure 1, are $q\overline{q}$ and qg interactions and each have 1 strong interaction vertex. Therefore, at leading order the ratio of $W + 1$ Jet/$W + 0$ Jets should be proportional to α_S, neglecting any dependence on the parton distribution functions.

The diagrams for some of the NLO corrections get a little more complicated. The $W + 0$ Jet production includes diagrams which have a strong interaction vertex (Figure 2) and are essentially the same as the leading order $W + 1$ Jet diagrams only the produced jet in this case fails to be detected. If the jets in question fail to pass a minimum transverse energy, E_T requirement the event will be counted as a $W + 0$ Jets event. Some of the NLO correction diagrams for $W + 1$ Jet (Figure 2) are similar to the leading order diagrams, with the addition of either gluon splitting or gluon radiation. Therefore, these diagrams have two strong interaction vertices. The events would normally be counted as $W + 2$ Jets events except one of the jets fails to be observed. In addition to the minimum jet E_T requirement mentioned above, there is the possibility that the two jets are too close in $\eta\phi$ space (within a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ where η and ϕ are the pseudorapidity and the azimuthal angle respectively) and thus detected as only one jet. Theoretical calculations of NLO corrections also include interference with loop diagrams.

A general cross section formula can be written as

$$\sigma = A_0 + \alpha_s A_1 + \alpha_s^2 A_2 \cdots + \alpha_s^n A_n \cdots \tag{1}$$

$$A_n = \int\int f(x_1, Q^2) f(x_2, Q^2) \mid M_n^{'} \mid^2 dx_1 dx_2 \tag{2}$$

where the α_S dependence has been factored out of the matrix element terms, $f(x, Q^2)$ are the parton distribution functions, x is the parton's initial momentum fraction, and Q^2 is the energy scale ($Q^2 = M_W^2$ in this experiment). If the parton distribution functions are independent of α_S, the α_S dependence of the cross sections can be determined by varying α_S in equation 1. The parton distribution functions are not, however, independent of α_S. In addition to being dependent on the renormalization scheme and the energy scale, these distribution functions are dependent on Λ_{QCD} in two ways. First one of the parameters in the fit used to determine the parton distribution functions is Λ_{QCD}. Second, the energy scale where the fit is performed is not the energy scale of the $W + n$ Jets production. Therefore, Λ_{QCD} has to be used to evolve the parton distribution functions to the appropriate energy scale for the experiment. Since α_S at a given energy scale can be written as a function of only the energy scale and Λ_{QCD}, any change in α_S is effectively a change in Λ_{QCD} and thus alters the parton distribution functions. The dependence on α_S in the parton distribution functions can either enhance or reduce the α_S dependence of the cross sections indicated by equation 1.

To compare the theory to the experimental results the following definition of the ratio $\mathcal{R}^{10} = W + 1$ Jet$/W + 0$ Jets is used:

$$\mathcal{R}^{10}(E_T^{jet} > E_T^{min}) = \frac{\sigma(W + 1\ Jet)}{\sigma(W + 0\ Jets)} = \frac{N(W + 1\ Jet)}{N(W + 0\ Jets)} \tag{3}$$

since experimentally the luminosity terms cancel out in the ratio, and where $N(W + 1\ Jet)$ and $N(W + 0\ Jets)$ are the number of events with a W plus one or zero jets with E_T above a cutoff E_T^{min} respectively.

FIGURES

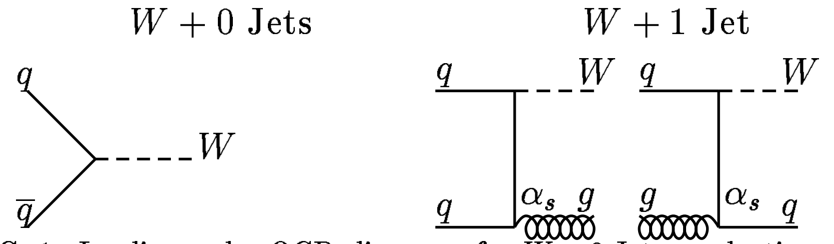

FIG. 1. Leading order QCD diagrams for $W+0$ Jets production on the left and $W+1$ Jet production on the right.

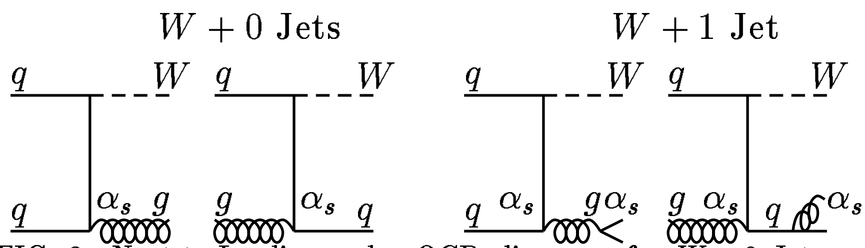

FIG. 2. Next-to-Leading order QCD diagrams for $W+0$ Jets production on the left and $W+1$ Jet production on the right.

III. EXPERIMENT

The data were taken using the DØ detector at the Fermilab Tevatron, which has been described in detail previously. [5] From the data sample candidates for a W decaying to an electron plus a neutrino ($W \rightarrow e\nu$) were selected with no jet multiplicity requirement. The electron candidates were required to have a E_T greater than 25 GeV, an electromagnetic fraction of 95% in the calorimeter shower and to match the expected electromagnetic shower shape. The electron had to be isolated from other objects in the event, and have a match between the calorimeter shower and a track in the central tracking detector.

The final electron criterion was a requirement of only one electron passing the above criteria, to eliminate Z decays to an electron and a positron. In addition to the electron requirements, the missing $E_T(\not{E}_T)$ in the event is required to be larger than 25 GeV. The jets for this analysis were based on a fixed cone algorithm with a radius of 0.7. Events with spurious jets due to beam conditions or detector effects were eliminated from the sample. The minimum E_T of a jet was fixed at 25 GeV for the main analysis, but was systematically varied to study the effect of this requirement on the comparison to next-to-leading order QCD.

IV. DATA

For a luminosity of 83 pb^{-1} during the 1994-1995 run of the DØ detector there were 36,891 $W \rightarrow e\nu$ candidates with electrons in the central part of the calorimeter. The dominant background is from multi-jet events where one of the jets is mismeasured, and another jet fluctuates to be predominantly electromagnetic. In this case, the event will appear to have an electron and a substantial $\not\!\!E_T$, the signal expected for a $W \rightarrow e\nu$ event. Other backgrounds include Drell-Yan and $Z \rightarrow ee$ where one electron is lost, and $Z \rightarrow \tau\tau$ where one τ decays to an electron and the other undergoes a hadronic decay.

The multi-jet background was estimated from data using a trigger without a $\not\!\!E_T$ requirement. The events were divided into two sets based on electron selection requirements. The first set required a good electron candidate in the event, while the second set required a non-electron (a candidate which fails the isolation, track match and shape requirements). The technique assumes that events with one good electron and a small amount of $\not\!\!E_T$ is a multi-jet event (background) in which a jet has fluctuated to look like an electron in the calorimeter. The $\not\!\!E_T$ distribution of the non-electron set of events is normalized to the good electron set of events in the low $\not\!\!E_T$ region ($\not\!\!E_T < 15$ GeV). The signal trigger sample is also divided up in the same way according to the good electron and non-electron criteria. The normalization factor is then applied to the non-electron data set from the trigger sample and the number of events in the signal region from both trigger data sets gives the fraction of multi-jet background. The multi-jet background determined using this method was 1.6% and 6.8% for $W + 0$ Jets and $W + 1$ Jet respectively.

The backgrounds from the electroweak processes, Drell-Yan, $Z \rightarrow ee$ and $Z \rightarrow \tau\tau$ were estimated using the ISAJET Monte Carlo [6]. The combined background fraction due to these processes is about 2% in the case of $W + 1$ Jet events and less than one percent for

$W + 0$ Jets events. For a requirement on the jet E_T of ≥ 25 GeV there are 33511 $W + 0$ Jets candidates and 2841 $W + 1$ Jet candidates before background subtraction. After subtracting both the multi-jet and electroweak backgrounds, 32835 $W + 0$ Jets and 2599 $W + 1$ Jet events remain and give a ratio of

$$\mathcal{R}^{10}_{exp} = 0.079 \pm 0.002^{stat} \pm 0.005^{sys} \tag{4}$$

The systematic error is dominated by the uncertainty in the jet energy scale.

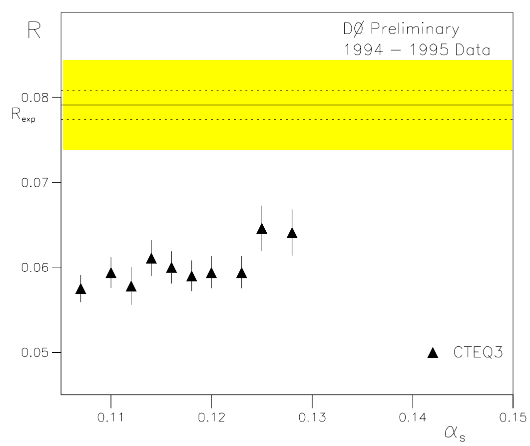

FIG. 3. NLO QCD $\mathcal{R}^{10}_{exp}$ compared to $\mathcal{R}^{10}_{theory}$ *vs.* α_S for the CTEQ3 set of parton distribution functions. The solid line is $\mathcal{R}^{10}_{exp}$, dashed lines are the statistical errors, and the shaded region is statistical and systematic errors in quadrature.

V. COMPARISON TO QCD

The measured value of $\mathcal{R}^{10}_{exp}$ was compared to a theoretical estimate using the DYRAD Monte Carlo and CTEQ3 parton distribution functions in which α_S has been varied by varying Λ_{QCD} in the fits. The values of $\mathcal{R}^{10}_{theory}$ are well below the value of $\mathcal{R}^{10}_{exp}$ even after accounting for the systematic uncertainties of the measurement (see Figure 3). In addition, the predictions of $\mathcal{R}^{10}_{theory}$ at $\sqrt{s} = 1800$ GeV show little or no dependence on the value of α_S, in sharp contrast to the predictions at $\sqrt{s} = 630$ GeV. The main difference between $\sqrt{s} =$

630 GeV and $\sqrt{s} = 1800$ GeV is in the momentum fraction of the initial partons in the W production. The $\sqrt{s} = 1800$ GeV data probes a much lower momentum fraction (x) region and this affects the relative contributions from the qg and $q\bar{q}$ processes. In the low x region probed by DØ the gluon distribution is not well constrained and is difficult to measure. It is possible that changes in the gluon distribution functions at low x are partially canceling the effects of increasing the value of α_S that was factored out in the cross section formula (see equation 1).

The results were checked to see if a dependence on the minimum jet E_T requirement was present. In this study the minimum jet E_T requirement was varied and new values of $\mathcal{R}^{10}_{exp}$ and $\mathcal{R}^{10}_{theory}$ were calculated. The results shown in Figure 4 indicate that the theory $\mathcal{R}^{10}_{theory}$ is systematically lower than data for all of the different minimum jet E_T conditions examined although the shapes of the two curves seem to be qualitatively similar.

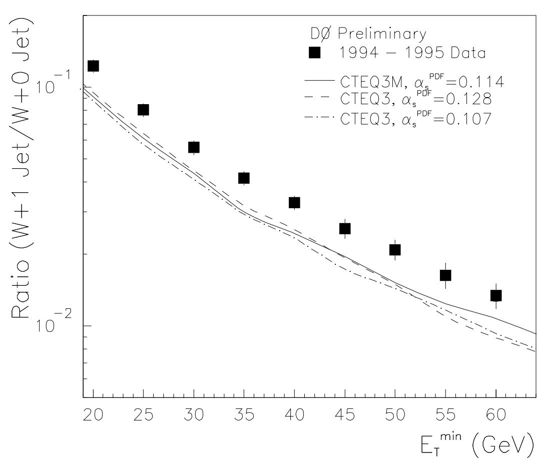

FIG. 4. NLO QCD $\mathcal{R}^{10}_{exp}$ compared to $\mathcal{R}^{10}_{theory}$ *vs.* minimum jet E_T for a subset of the CTEQ3 set of parton distribution functions.

VI. CONCLUSIONS

DØ has made a preliminary measurement of the ratio of production cross sections for $W + 1$ Jet to $W + 0$ Jets using the data collected during the

1994-1995 run of the Fermilab Tevatron. The measured ratio is $\mathcal{R}_{exp}^{10} = 0.079 \pm 0.002^{stat} \pm 0.005^{sys}$. A comparison to NLO QCD calculations has shown these calculations to be consistently lower than the data for the range of α_S values currently available for the CTEQ3 parton distribution functions.

ACKNOWLEDGMENTS

We thank the staffs at Fermilab and the collaborating institutions for their contributions to the success of this work, and acknowledge support from the Department of Energy and National Science Foundation (U.S.A.), Commissariat à L'Energie Atomique (France), Ministries for Atomic Energy and Science and Technology Policy (Russia), CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), and the A.P. Sloan Foundation.

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